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Fabrication Method of Double-Microlens Array Using Self-Alignment Technology

Kazuya KITAMURA*, Kuniaki OKADA, Noboru FUJITA, Yukiko NAGASAKA,
Minoru UEDA, Yoshihiro SEKIMOTO and Yukio KURATA

Precision Technology Development Center, SHARP Corporation, 2613-1 Ichinomoto-cho, Tenri-shi, Nara 632-8567, Japan

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A fabrication method for double-microlens arrays with self-alignment technology (SAT) is proposed. To satisfy the tolerance of the alignment of a two-layer-lens array, we developed a new fabrication method without an alignment process. Using SAT, we achieved a brightness increase of 30% compared with the conventional single-layer microlens array.

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KEYWORDS: double microlens array, self-alignment technology, LCD projector, brightness, dry etching, exposure, photo-polymerization method, three-dimensional shape

1. Introduction

For the large displays of rear projection systems using a high-definition liquid crystal display (LCD), the reduction of the panel cost and the improvement in the brightness of the screen are the most important objectives.

Since in a conventional 3-LCD (3 board LCD) projector, three LCDs corresponding to red (R), green (G), and blue (B) are used, a rise in cost is unavoidable. In a single-LCD projector, because of the use of color filters, the decrease in brightness poses a problem.

Therefore, a rear projector utilizing the new single-LCD system which does not use color filters is proposed.[1)]

In this system called the color-filterless single-LCD projection system, by use of dichroic mirrors, white light is separated into three colors, R, G and B, and then distributed to each pixel (see Fig. 1).

Since color filters are not used in this system, it has a brightness of approximately three times that of a single-microlens array (MLA) projector with color filters, but achieving further improvement in the brightness is the most important issue.

In order to increase the brightness of the color-filterless single-LCD projector, we propose that two layers of an MLA are attached to a liquid crystal panel (LCP). We have developed a new processing technology for two-layer MLAs (double-microlens array (D-MLA)). We call this processing technology the self-alignment technology (SAT) process. In this paper, the SAT process for the D-MLA is reported.

2. Design

The structure of the D-MLA is shown in Fig. 2. In this D-MLA, which consists of two layers, the first MLA is situated on the light source side, and the second MLA is situated near the black matrix layer. The focal point of the first MLA is near the black matrix.

The parallel rays incident to the first MLA are focused on the black matrix. The chief ray of the R light is perpendicular to the LCP, and the chief rays of the G and B lights are at an angle θ to the LCP. The chief rays of G and B light are refracted parallel to that of R light by the second MLA. So

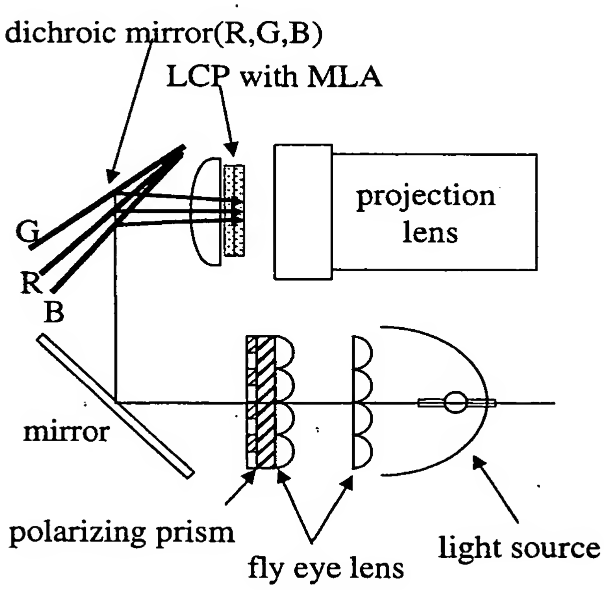

Fig. 1. Schematic of the color-filterless single-LCD Projection System.

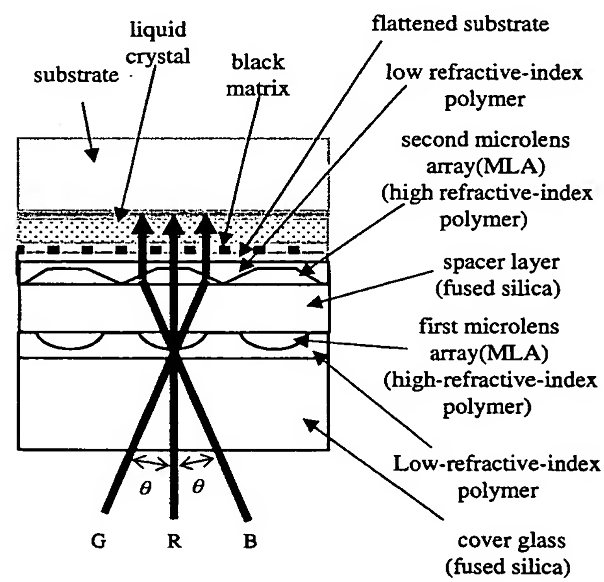

Fig. 2. Layer structure of the D-MLA.

*E-mail address: kitamura.kazuya@sharp.co.jp

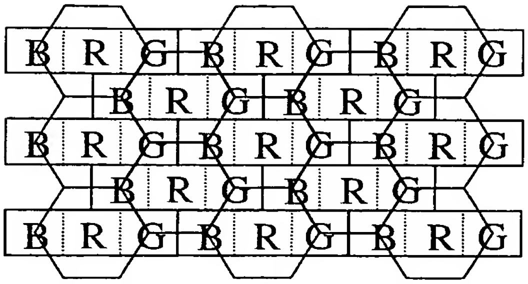

Fig. 3. Layout of first MLA, second MLA and pixels.

the chief ray of each color is parallel to the others, and perpendicular to the LCP. For this reason, the rays of the R, G and B lights incident on the projection lens are not blocked by the projection lens, and it is evenly colored.

The first MLA has a honeycomb structure. The layouts of the first MLA, the second MLA and the pixels are shown in Fig. 3.

The oblique angle of the second MLA depends on the difference in refractive index between the high-refractive-index polymer and the low-refractive-index polymer, and the incident angle of the chief rays of the G and B lights at the first MLA. The oblique angle of the second MLA is 50°, in this study, at which the brightness is maximum.

When the difference in refractive index between these two polymers is large, the oblique angle of the second MLA becomes small. Therefore, the aspect ratio of the height of the second MLA to the length of the basal plane is reduced, and processing is easy. Here, we considered reliability and process ability to be desirable, and thus we decided to use the polymers indicated below. The index of 588 nm (wavelength) of the high-refractive-index polymer is 1.59, that of the low-refractive-index polymer is 1.41.

The specification of the oblique angle of the second MLA is 50° ± 5° (see Table. I). In this variation in oblique angle (±5°), the chief rays of the G and B lights vary the angle of incidence to the LCP. Its value of the variation is about 2.7°, but it is a small variation of the incident angle to decrease in brightness. Its decrease in brightness is −3.7% in our simulation.

We simulated that the increase in brightness was 50% in design value, so we determined that the target efficiency of the D-MLA was 1.3 times that of the single-MLA in consideration of the fabrication tolerances and the variations in this process.

3. Self-Alignment Technology

The important features of the processing of the second MLA are discussed below. The first feature is that the angle of the side wall should be close to 90°. The second feature is that the alignment accuracy between the first MLA and the second MLA is good.

Table I. Design of second MLA.

oblique angle of second MLA	angle of sidewall	height of second MLA
50°	more than 80°	25 µm

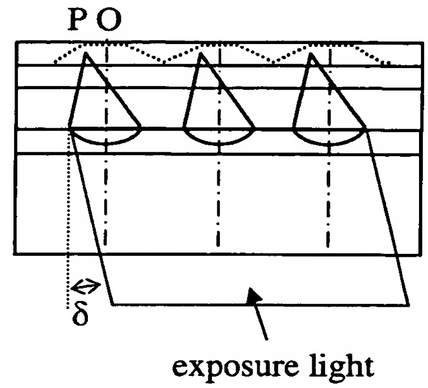

Fig. 4. Schematic of the SAT process.

If the photopolymerization processing method with a stamper is used, certain disadvantages will arise concerning the points indicated above. That is, for the first point, the stamper angle must be approximately 15° to demold the second MLA, and for the second point, it is very difficult to align the first MLA and the second MLA accurately, with the 100 µm spacer layer inserted. Therefore we have developed a new processing method for the second MLA which does not have a complicated alignment process.

This processing method is called the SAT process, that is, the second MLA is formed at the focal point of the first MLA by using focusing property. The schematic of the SAT process is shown in Fig. 4. The i-line (wavelength = 365 nm) for the exposure was set to be parallel light, this parallel light is incident to the first MLA at a 0° incident angle, and a condensing point arises at point O which is near the focal point.

This point O corresponds to the optical axis of the first MLA. For the next step, the first MLA is rotated δ together with the substrate, and then the condensing point arises at point P which corresponds to the incident angle δ. At this time, if the focal length of the first MLA is defined as f, the following formula is realized.

$$\mathrm{OP} = f^{*} \tan\delta.$$

On the basis of this relation, if we intend to expose the resist on P to be the desired thickness, we should irradiate it at the incident angle δ with the appropriate exposure dose.

For comparison, the negative resist shown in Table II was used. This negative resist was chosen for the following reasons. The first reason is that the required height of the second MLA is very high, that is, approximately 25 µm or

Table II. Specification of the resist.

Resist	Negative Resist
Viscosity	1600 CPS
Exposure Sensitivity	200–400 mJcm^{-2} (at 405–420 nm)
Resolution(Line/Space)	20/20 µm
Thickness of resist	32 µm
r.p.m. of spincoater	1150 rpm

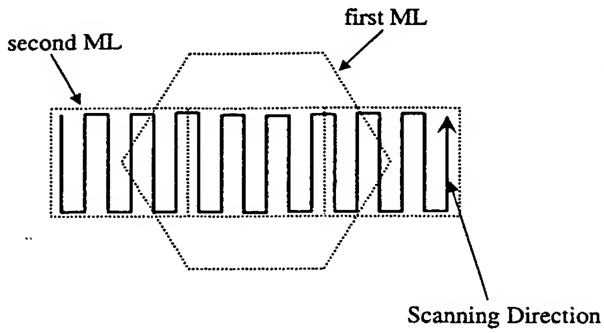

Fig. 5. Track left by point P.

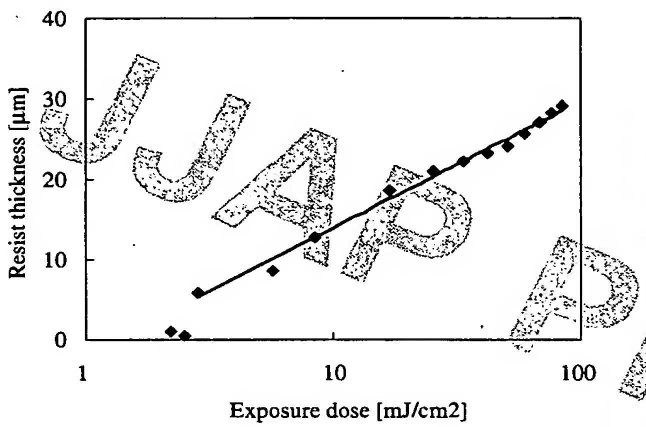

Fig. 6. Dependence of negative resist thickness on exposure dose.

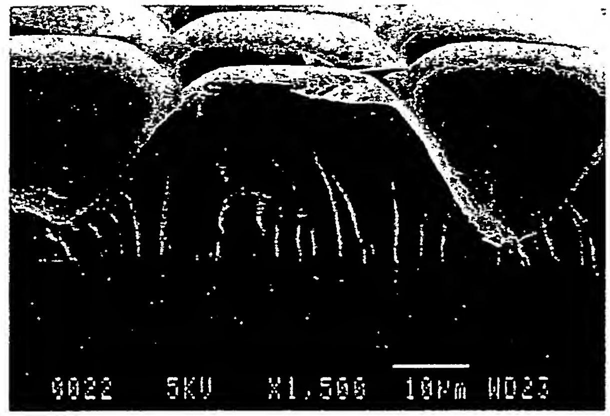

Fig. 7. Scanning electron microscopy photograph of the section parallel to the long side of the second MLA.

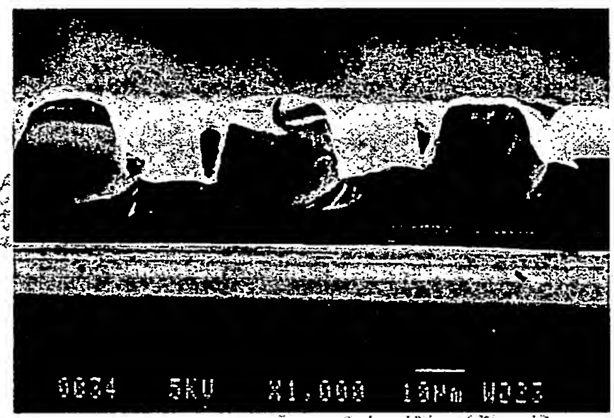

Fig. 8. Scanning electron microscopy photograph of the section perpendicular to the long side of the second MLA.

more. The second reason is that the negative resist needs to be cured on the focal point of the first MLA because of the form of the second MLA shown in Fig. 4. The track left by point P is shown in Fig. 5. The scanning direction is indicated in this figure.

The relationship between the negative resist thickness and the exposure dose is shown in Fig. 6. The negative resist thickness increases in proportion to the logarithm of the exposure dose. This result confirms that it is possible to control the negative resist thickness by changing the exposure dose.

The resist pattern after the development of the cross section as seen from the longitudinal direction of the second MLA, is shown in Fig. 7. The design value of 50° of the oblique angle is achieved.

On the other hand, the resist pattern after the development of the cross section as seen from the direction perpendicular to the longitudinal direction of the second MLA, is shown in Fig. 8. Since the numerical aperture (NA) of the first MLA is 0.3 and the wavelength of the incident exposure light is 365 nm, the beam spot diameter of the first MLA is 1.5 μm, as calculated using Airy's disk (=1.22*wavelength/NA). It is estimated that the angle of the side wall of the second MLA became rounded due to the spreading of the beam spot. The wall height is 25 μm, and the round of the edge on the top surface of the second MLA is approximately 1.5 μmR, so it is estimated that the angle of the side wall is less than 86.5°. The measured angle of the side wall is more than 80°, as shown in Fig. 8.

4. Etching Process

The form of the negative resist after the development (discussed in §3) is transferred to a high-refractive-index polymer by dry etching. We used the reactive ion etching method with high-density plasma.

There are two important features in this process. The first feature is that we must maintain the shape of the negative resist to be as unchanged as possible. The second feature is that the selectivity of the high-refractive-index polymer to the negative resist is nearly 1.0. Therefore we perform the anisotropic etching by the reactive ion etching method with high-density plasma.

We used Ar, C_3F_8 and N_2 for the etching gases. The dependence of the anisotropy and the etching rate of the polymer on the gas flow rate of N_2 is shown in Fig. 9. R (shown below) is the evaluated value of the anisotropy of the etching. That is the ratio of the quantity of the side etching to that of the depth direction etching. This indicates that the

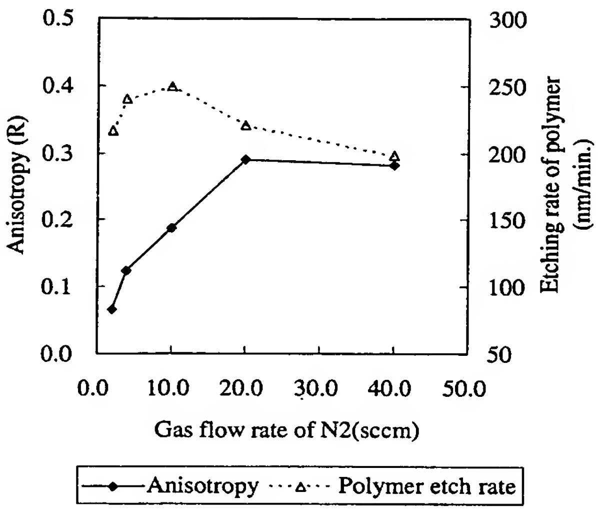

Fig. 9. Dependence of the anisotropy and etching rate of the polymer on the gas flow rate of N_2.

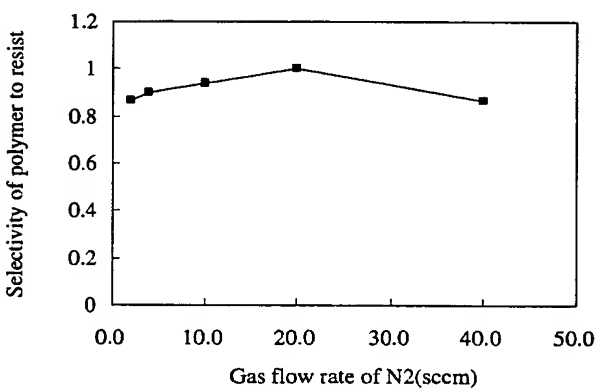

Fig. 10. Dependence of the selectivity of the polymer to the resist on N_2 gas flow rate.

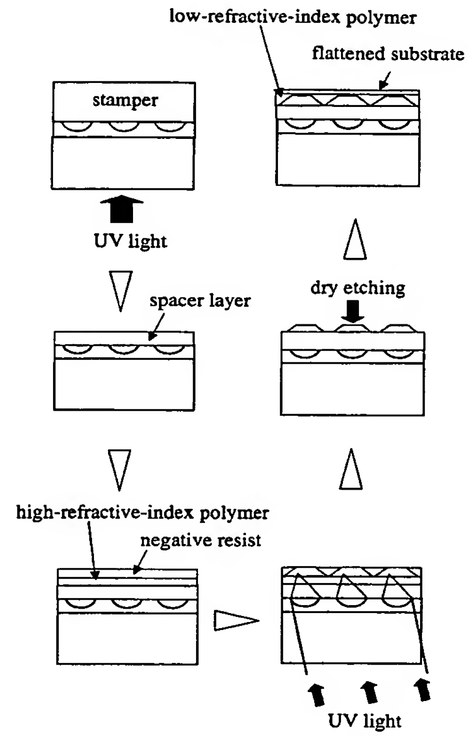

Fig. 11. Fabrication process of the D-MLA.

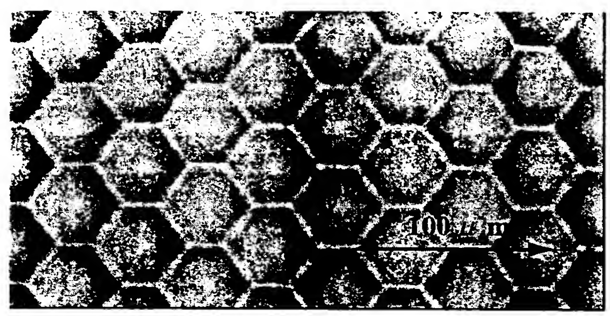

Fig. 12. Microphotograph of the first MLA as seen from above.

optimum condition for achieving the anisotropy is an N_2 gas flow rate of 20 sccm.

The dependence of the selectivity of the polymer to the resist on the gas flow rate of N_2 is shown in Fig. 10. When the gas flow rate of N_2 is 20 sccm, the selectivity is maximum at 1.0. Therefore, the condition of N_2:20 sccm is the optimum one.

5. Fabrication

The process flow diagram is shown in Fig. 11. First, the first MLA is formed by the photo-polymerization (2P) method using a stamper made of silica. Next, the spacer layer is adhered to the first MLA. The spacer layer is then lapped and polished to a predetermined thickness, the high-refractive-index polymer for the material of the second MLA is applied to the spacer layer, and then, the negative resist is applied to it. Then, the negative resist is exposed to obtain the form of the second MLA according to the SAT process. After exposure, this form is transferred to the high-refractive-index polymer by dry etching, the flattened substrate is adhered using the low-refractive-index polymer to the second MLA, then the flattened substrate is lapped and polished to a predetermined thickness, and then a black matrix layer is formed on top of the structure. Thus, the substrate of the liquid crystal panel is completed.

The first MLA after the 2P method, as seen from above, is shown in Fig. 12. Its form is a honeycomb structure as mentioned above, and the gap between the lenses is 0.5 μm or less, so it is small not to decrease brightness.

Measurements indicated that the efficiency of the D-MLA was 30% higher than that of a single-MLA.

6. Conclusion

We developed the processing technology for a D-MLA. Using this technology, we are able to fabricate any three-

dimensional shape and achieve easy alignment and good accuracy.

We fabricated the second MLA which has an oblique angle of 50°, a sidewall angle of 80° or more and an aspect ratio of 1.2 (narrow side).

This new technology expands the possibility of processing for optical elements which need a large aspect ratio and a high alignment accuracy, and it is useful for various microoptical elements.

Acknowledgment

The authors are grateful to Mr. H. Hamada, Mr. H. Nakanishi, Mr. Y. Kume and the members of SD-PT of Sharp Corporation for their helpful discussions and insights.

1) H. Hamada, H. Nakanishi, F. Funada and K. Awane: IDRC '94 DIGEST (1994) 422.

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